

*THE EFFECT OF DENSITY
ON THE REPEATED-LOAD STRENGTH
PROPERTIES OF BITUMINOUS CONCRETE*

NOVEMBER 1959

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*Joint
Highway
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Project*

*PURDUE UNIVERSITY
LAFAYETTE INDIANA*

by

J. H. DENNIS

Final Report

THE EFFECT OF DENSITY ON THE REPEATED-LOAD STRENGTH
PROPERTIES OF BITUMINOUS CONCRETE

TO: E. B. Woods, Director
Joint Highway Research Project

FROM: H. L. Michael, Assistant Director
Joint Highway Research Project

November 19, 1959

File: 2-4-11,
Project: C-36-6N

Attached is report entitled, "The Effect of Density on the Repeated-Load Strength Properties of Bituminous Concrete", by J. H. Dennis, Graduate Assistant on our staff. The research reported was performed under the direction of Professor W. H. Goetz of our staff and was used by Mr. Dennis as his thesis for the MSCE Degree.

This study is primarily concerned with the plastic deformations obtained through the repeated-load testing of bituminous concrete surfacing mixtures.

The report is presented for the record.

Respectfully submitted,

H. L. Michael

H. L. Michael, Secretary

HLM:pg

Attachment

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Final Report

THE EFFECT OF DENSITY ON THE REPEATED-LOAD STRENGTH
PROPERTIES OF BITUMINOUS CONCRETE

by

J. H. Dennis, Graduate Assistant

Joint Highway Research Project
Project No: G-36-6M
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Purdue University
Lafayette, Indiana

November 19, 1959

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TABLE OF CONTENTS

	<u>Page</u>
LIST OF TABLES	iv
LIST OF ILLUSTRATIONS.	v
ABSTRACT	vi
INTRODUCTION	1
REVIEW OF LITERATURE	3
Repeated Loading of Bituminous Materials.	3
Repeated Loading of Soils	6
MATERIALS.	7
Aggregates.	7
Asphalt	12
APPARATUS AND PROCEDURES	14
Preparation of Slab-Type Specimens.	14
Preparation of Cylindrical-Type Specimens	17
Density Determinations.	19
Repeated-Load Test.	21
Hveem Stabilometer Test	25
RESULTS.	28
Repeated-Load Tests	29
Cylindrical-Type Specimens	32
Slab-Type Specimens.	39
Comparison of Cylindrical and Slab-Type Specimens	40
Hveem Stabilometer Tests.	41
Comparison of Results from Hveem Stabilometer and	
Repeated-Load Tests.	43
CONCLUSIONS.	46
SUGGESTIONS FOR FURTHER RESEARCH	47
BIBLIOGRAPHY	48
APPENDIX	50

LIST OF TABLES

<u>Table No.</u>		<u>Page</u>
1	Specification Limits for Hot Asphaltic Concrete Surface Type B and Mixture Composition Used for Laboratory Specimens.	8
2	Specification Limits for Corps of Engineers Surface Mix (Maximum Aggregate Size - 1/2") and Mixture Composition Used for Laboratory Specimens.	9
3	Gradation of Mineral Filler	11
4	Results of Tests on Asphalt Cement.	13
5	Typical Data Sheet for Repeated-Load Test - Cylindrical Specimens.	33
6	Results of Repeated-Load Test on Cylindrical Specimens - Indiana Gradation.	50
7	Results of Repeated-Load Test on Cylindrical Specimens - Corps of Engineers Gradation	52
8	Results of Hveem Stabilometer Test - Indiana Gradation.	53
9	Results of Hveem Stabilometer Test - Corps of Engineers Gradation	54
10	Density Determinations of Cylindrical Repeated-Load Test Specimens.	55
11	Results of Repeated-Load Test - Indiana Gradation - Slab Specimens 12 x 12 x 2-1/2 inches	56

LIST OF ILLUSTRATIONS

<u>Figure No.</u>		<u>Page</u>
1	Gradation Curves for Indiana AH Type (B) Surface Mixture and Corps of Engineers Surface Mixture	10
2	Pneumatic Vibrator and Mold for Slab Specimens	15
3	Electric Air Hammer and Mold for Slab Specimens.	16
4	Pneumatic Vibrator and Mold for Cylindrical Specimens.	18
5	Cores and Cored Slab Specimen	20
6	Repeated-Load Test Apparatus.	23
7	Hveem Stabilometer.	27
8	Typical Data of Repeated-Load Test (Log-Log Plot) Cylindrical Specimen	30
9	Typical Data of Repeated-Load Test - Arithmetic Plot - Cylindrical Specimen.	31
10	Repeated-Load Test Results - Indiana Gradation - Permanent Deformation per Load Repetition - Cylindrical Specimens.	34
11	Repeated-Load Test Results - Corps of Engineers Gradation - Permanent Deformation per Load Repetition - Cylindrical Specimens	35
12	Repeated-Load Test Results - Indiana Gradation - Deformation Index - Cylindrical Specimens.	36
13	Repeated-Load Test Results - Corps of Engineers Gradation - Deformation Index - Cylindrical Specimens.	37
14	Hveem Stabilometer Results - Indiana Gradation	42

ABSTRACT

Dennis, John Harold. M.S.C.E., Purdue University, January 1960. The Effect of Density on the Repeated-Load Strength Properties of Bituminous Concrete. Major Professor: William H. Goetz.

This study is concerned primarily with the plastic deformations obtained through the repeated-load testing of bituminous concrete surfacing mixtures. Parameters were calculated from these plastic deformations and were compared with results from the Hveem Stabilometer test. In the initial part of this investigation an attempt was made to obtain a slab-type specimen which would produce realistic results by the repeated-load test. Since means were not found to compact a slab-type specimen to a uniformly high density, a cylindrical-type specimen was used as an alternative for the repeated-load test.

In comparing the results of the repeated-load test with the Hveem Stabilometer test results, it appears that the mixtures are evaluated differently by the two methods. The results from this investigation are not suitable for evaluating bituminous concrete surface mixtures in regard to rutting and shoving.

THE EFFECT OF DENSITY ON THE REPEATED-LOAD STRENGTH PROPERTIES OF BITUMINOUS CONCRETE

INTRODUCTION

The object of this study was to obtain parameters from the repeated-load test which will define the strength properties of a bituminous concrete surface mixture. It was specifically desired to use the repeated-load test in measuring plastic deformations of bituminous concrete surface mixtures which might provide information useful in solving the rutting and shoving problem. Rutting, which is the longitudinal grooving of the pavement in the wheel tracks, and shoving, which is permanent distortion which results in transverse waves, are caused when repeated heavy loads result in plastic deformations which accumulate to form objectionable depressions. The most critical condition for rutting and shoving is slowly-moving, heavily-loaded vehicles. Since these types of failure are caused by repeated loads, it was speculated that the repeated-load test could simulate traffic conditions and possibly show why they occur.

It was desired to determine parameters using the permanent (plastic) deformation recorded from the repeated-load test, and then comparing them with a conventional stability value (Hveem Stability).

Only surface-type mixtures were used in the study, and

since the specimens rested on a rigid base while being tested, the results are applicable to the condition of a bituminous concrete overlay over a portland cement concrete pavement.

As a preliminary part of the study it was desired to obtain a slab-type specimen of suitable size so that a laboratory test which more closely approximates the road prototype might be had. Due to the fact that means were not found to compact a slab specimen to a high and laterally uniform density, this phase of the planned study was minimized and a cylindrical specimen was used instead.

REVIEW OF LITERATURE

The problem of rutting and shoving in the wheel-track areas of bituminous concrete overlays on deteriorated portland-cement concrete pavements was of a minor extent in Indiana until about 1951. Since then, with the increasing number and weight of trucks on the highways, these types of failure have become a major problem. There is at present no standard design method of bituminous concrete using a repeated-load type of test. Also there is no design method which can predict whether or not a pavement will fail by densification under traffic to the degree that rutting and shoving will result.

Repeated Loading of Bituminous Materials

Two studies have been conducted by the Joint Highway Research Project of Purdue University on the rutting problem. The first of these was of a fundamental character using sheet-asphalt and bituminous-concrete specimens of rational size and tested by rational procedures (11)¹. The second study, conducted to relate these data to field conditions, was performed on bituminous-concrete specimens of irrational size, molded in the laboratory, cored from laboratory-molded slab specimens, and cored from pavements (6). Goetz, McLaughlin,

1. Numbers in parentheses refer to references listed in the bibliography.

and Wood (3) have concluded that rutting failures are caused by plastic flow of the mixture.

These authors stated in their report on "Load Deformation Characteristics of Bituminous Mixtures Under Various Conditions of Loading" that they approached the laboratory solution of the rutting problem "first from the fundamental considerations of the stress-deformation characteristics of asphaltic mixtures as measured by various methods of test, and secondly from the application of these test methods to the evaluation of bituminous concrete." The problem was not solved, but certain relationships were found among the factors governing the load-carrying characteristics of bituminous mixtures that should aid in the solution of the problem. One of these fundamental relationships which relates the compressive strength of a bituminous mixture to the rate of loading and temperature is of the form, $x_0 = A^{Bx_1}(Cx_2 + D)$, where x_0 = maximum unconfined compressive stress, psi; x_1 = rate of deformation, in./min.; x_2 = temperature, °F; and A, B, C, D are constants. This relationship has been established for two basic types of bituminous mixtures and for a variety of test conditions. The authors concluded from the results of the repeated-load tests on bituminous mixtures that this type of test might provide valuable information concerning the rutting problem. It might also show the plastic nature of the bituminous mixture and possibly give a measure of the endurance limit which they defined as the applied stress that can be cycled without excessive shear deformations occurring or the

stress level at which no further increase in permanent deformation occurs after a small number of load applications. Finally, in their work on confinement in a thin layer the results showed that to obtain the same compressive strength in a conventional triaxial test as that obtained from testing the mixture in a relatively thin layer, a confining pressure equal to or greater than the unconfined compressive strength of the mixture would be necessary.

In 1952, Hveem and Vallergera (5) reported on a study they had made on density versus stability. Their conclusion that there is a high degree of correlation between stabilometer results and pavement performance and little correlation between stabilometer results and the density of the mixture (except that the stabilometer results are invariably low when the void spaces are filled or nearly filled with asphalt) is of interest because if repeated loading tends to fill the void spaces of a bituminous mixture then it might also lower the stability. In 1950 it was reported by Monismith and Vallergera (8), in a study of the relationship between density and stability of asphaltic paving mixtures, that there is a relationship between density and stability and that it is dependent upon the criterion used to determine stability. For the method they used in determining stability (a stress corresponding to a particular strain) an increase in density resulted in an increase or decrease in stability depending upon the composition of the mix and the range of densities considered. From these results it can be concluded that there is a

relationship among voids filled with asphalt, density, and stability. And since rutting is usually accompanied by a change in density and amount of voids filled with asphalt, there should be a relationship between rutting and stability.

Repeated Loading of Soils

There has been a great deal of work done on the repeated-load testing of soils. However, it did not seem pertinent to report the results of all the literature on this subject. In a report on the repeated-load testing of soils by Tschebotarioff and McAlpin (10) there is shown a plot of number of repetitions of load (log scale) versus plunger penetration for granular soils (sands), which is closely resembled by the plots of McLaughlin, Goetz, and Wood showing number of load repetitions (log scale) versus permanent deformation for bituminous mixtures. This comparison shows that somewhat similar relationships are obtained from the repeated-load testing of soils and bituminous concrete mixtures.

MATERIALS

Bituminous concrete mixtures of two gradations were used in this investigation. One gradation was chosen to meet the specifications of the State Highway Department of Indiana for Hot Asphaltic Concrete Surface-Type B (Medium Texture) (9), and the other to meet the Corps of Engineers specifications (2) for Surface Mix (Maximum Aggregate Size - 1/2"). The composition limits for the Indiana Type B and the Corps of Engineers Surface Mixes are shown respectively in Tables 1 and 2, together with the compositions of the mixtures selected for this study. Figure 1 shows the grain size distribution curves for the aggregate gradings selected.

Aggregates

The coarse aggregate (material retained on the No. 8 sieve) used in this investigation was a crushed limestone obtained from the Ohio and Indiana Stone Company, Greencastle, Indiana, and the fine aggregate (material passing the No. 8 sieve), with the exception of the material passing the No. 200 sieve, was a local sand obtained from the Western Indiana Sand and Gravel Company, Lafayette, Indiana. A commercial mineral filler was used to supply the material passing the No. 200 sieve and it was obtained from the Ohio and Indiana Stone Company, Greencastle, Indiana. The gradation of the mineral filler is given in Table 3.

Table 1

Specification Limits for Hot Asphaltic Concrete Surface -
Type B and Mixture Composition Used for Laboratory Specimens

Passing Sieve	Retained on Sieve	Composition Limits Percent		Composition Selected Percent
		Minimum	Maximum	
1/2 inch	3/8 inch	2	14	12
3/8 inch	No. 4	20	50	36
No. 4	No. 6	0	11	5
No. 6	No. 8	0	11	5
No. 8	No. 16	5	20	11
No. 16	No. 50	10	25	23
No. 50	No. 100	2	17	3
No. 100	No. 200	1	5	2
No. 200	-	3	5	3
Total Retained on No. 6		45	55	53
Bitumen		5.5	7.5	4.5-7.5

Table 2

Specification Limits for Corps of Engineers Surface Mix
(Maximum Aggregate Size - 1/2") and Mixture Composition
Used for Laboratory Specimens

Passing Sieve	Composition Limits Percent		Passing Sieve	Retained on Sieve	Composition Selected Percent
	Maximum	Minimum			
1/2 inch	100	100	1/2 inch	3/8 inch	8
3/8 inch	100	84	3/8 inch	No. 4	5
No. 4	85	60	No. 4	No. 8	13
No. 8	73	46	No. 8	No. 10	12
No. 16	60	35	No. 16	No. 30	11
No. 30	48	25	No. 30	No. 50	9
No. 50	36	19	No. 50	No. 100	10
No. 100	24	11	No. 100	No. 200	11
No. 200	9	4	No. 200	-	5
Bitumen	5	8			6 - 8

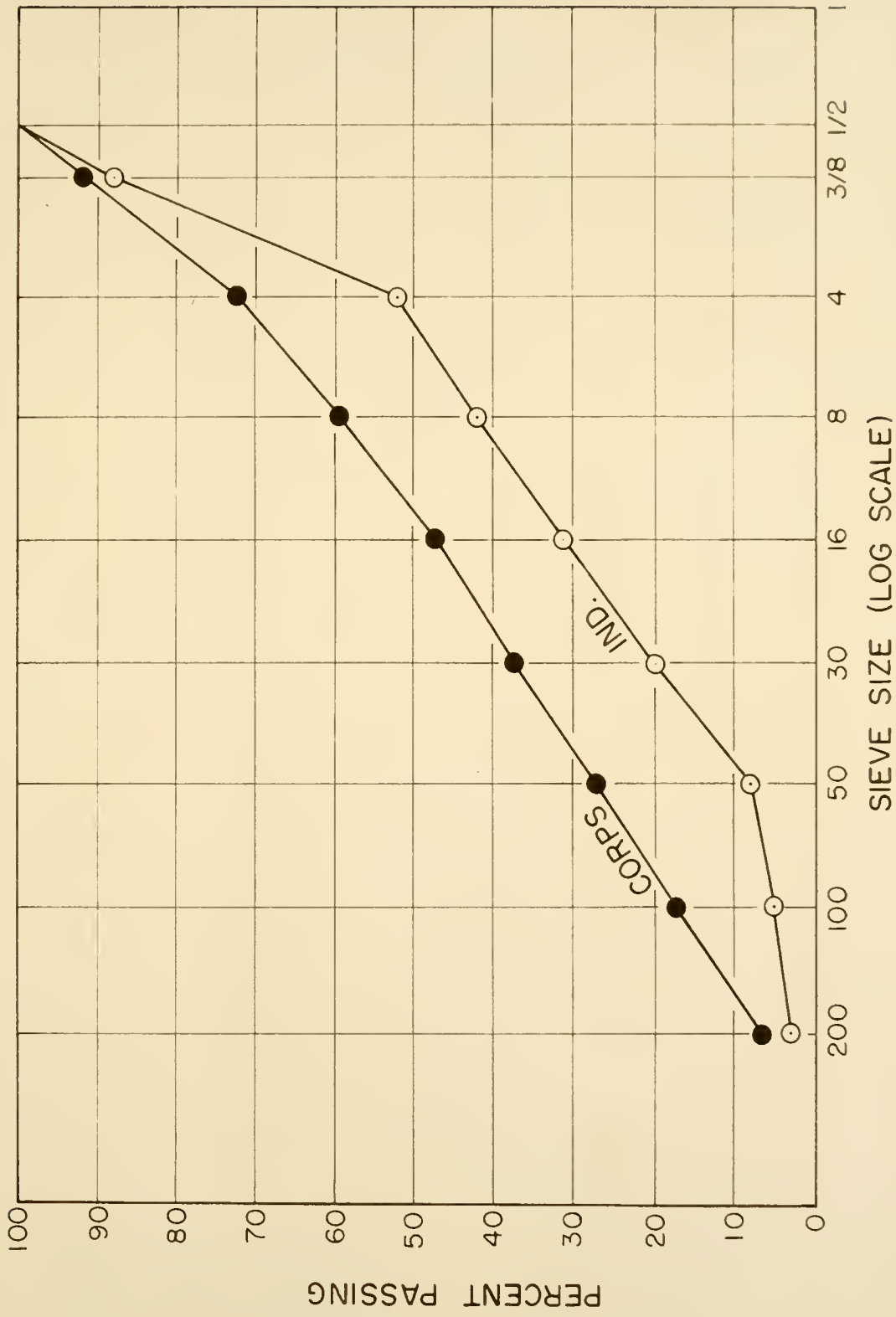


FIG. 1. GRADATION CURVES FOR INDIANA AH TYPE (B) SURFACE MIXTURE AND CORPS. OF ENGINEERS SURFACE MIXTURE.

Table 3
Gradation of Mineral Filler

Passing Sieve	Retained on Sieve	Percent
No. 30	No. 50	0.5
No. 50	No. 100	4.0
No. 100	No. 200	10.3
No. 200	-	85.2

The coarse aggregate had the following properties:

Bulk specific gravity = 2.68

Apparent specific gravity = 2.73

Absorption = 1.13%

The fine aggregate had the following properties:

Bulk specific gravity = 2.61

Apparent specific gravity = 2.71

Absorption = 1.56%

The coarse and fine aggregates were sieved into sieve-size fractions, as indicated in Tables 1 and 2, and then recombined into batches of the proper size for each specimen to be made. For the Indiana Type B gradation an additional sieve (No. 30) was included for control of the fine aggregate fraction. The 23 percent of the aggregate between the No. 10 and the No. 50 sieves was divided: 11 percent between the No. 10 and No. 30 sieves and 12 percent between the No. 30 and No. 50 sieves.

Since the mineral filler did not all pass the No. 200 sieve, enough of the mineral filler was used to give the correct amount of material passing the No. 200 sieve, and an amount equal to the portion of the mineral filler not passing the No. 200 sieve was deducted from the amount of fine aggregate used.

Asphalt

A 60-70 penetration grade asphalt cement furnished by the Texas Company from their Port Neches refinery was used for all specimens. Standard test results on this asphalt are given in Table 4.

Table 4
Results of Tests on Asphalt Cement

Test	Result
Specific Gravity at 77°F	1.031
Softening Point, Ring and Ball, °F	122
Ductility at 77°F, 5 cm./min., cm.	200+
Penetration, 100 grams, 5 sec., 77°F	66
Penetration, 200 grams, 60 sec., 32°F	17
Penetration, 50 grams, 5 sec., 115°F	300+
Flash Point, Cleveland Open Cup, °F	620
Solubility in CCl ₄ , percent	99.92
Oliensis Spot Test	Neg.

APPARATUS AND PROCEDURES

The five main divisions of this section are concerned with preparation, testing, and performing density determinations on the specimens. Both types of specimens, the slab and cylindrical, are discussed under these headings.

Preparation of Slab-Type Specimens

In the preparation of the slab-type specimens, the batched aggregate was heated to a temperature of $300 \pm 10^{\circ}\text{F}$ and the asphalt was heated to a temperature of $275 \pm 5^{\circ}\text{F}$. The desired amount of asphalt was weighed into the aggregate and they were then placed in a Hobart mixer and mixed for three minutes. The mixtures were then compacted into 12-inch square slabs by one of the following two methods. For one method, a pneumatic vibrator, Cleveland Type F.A.C., having a 1-1/4 inch piston, operated at a line pressure of 60 pounds per square inch, with a vibrational frequency of 3170 cycles per minute and an air consumption of 8.4 cubic feet per minute was used to compact the mixture. A steel foot-or-base-plate 3-inches by 6-inches by 1/4-inch in thickness was attached to the vibrator to serve as a compacting foot. For the other method an electric air hammer was fitted with a steel tamping foot 4-inches square by 3/4-inch thick. Figures 2 and 3 show the compaction equipment and typical specimens.

The specimens were compacted to a given height of 2-1/2



Fig. 2 PNEUMATIC VIBRATOR AND MOLD
FOR SLAB SPECIMENS

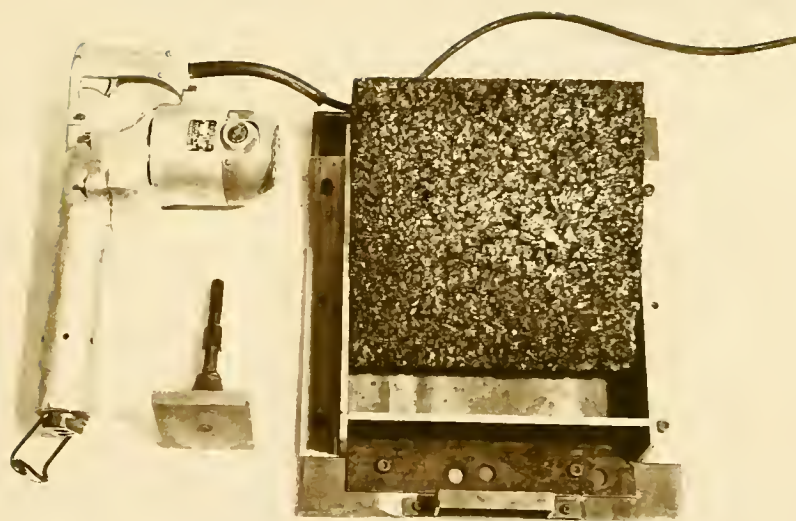


Fig. 3 ELECTRIC AIR HAMMER AND MOLD
FOR SLAB SPECIMENS

inches. This height was chosen so that cores could be taken from the slabs and tested in the Hveem Stabilometer. For the initial part of the investigation of the slab-type specimens it was desired to obtain a density of 142 pounds per cubic foot, as this value would be the approximate average density of a newly-constructed bituminous concrete overlay (7).

After testing some specimens at a density of 142 pounds per cubic foot it was found that the specimens did not densify enough under a reasonably small enough number of load repetitions so it was desired to compact the specimens to a higher density. The electric air hammer was used to try to compact the specimens to a higher density, but it was not possible to obtain a specimen with a uniformly high lateral density.

Preparation of Cylindrical-Type Specimens

For the cylindrical-type specimen the aggregate and asphalt were heated to the same temperatures as for the slab-type specimens. The aggregate and asphalt were then mixed for two minutes in the Hobart mixer. The mixed material was then placed in a preheated, 4-inch diameter split steel mold in three approximately equal layers. Each layer was rodded 25 times with a steel rod 17-inches long, 5/8-inch in diameter and weighing about 1.4 pounds. The material was then vibrated for one minute with the pneumatic vibrator used in compacting the slab-type specimens. The base plate used on the pneumatic vibrator for this operation was 2-1/2-inches in diameter and 1/2-inch thick. Figure 4 shows the mold and compaction equipment.



Fig. 4 PNEUMATIC VIBRATOR AND MOLD
FOR CYLINDRICAL SPECIMENS

The material was then compressed in a compression testing machine to the height required for the desired density. The specimens were then removed from the mold and allowed to cool to room temperature.

The desired densities for the cylindrical specimens ranged from 138 to 152 pounds per cubic foot. Since it was found that the repeated-load test did not densify the specimens, but that it made them less dense, the above density range was chosen so that the effects of the repeated-load test could be determined over the entire range of densities encountered from as-constructed bituminous-concrete overlays to fully traffic-compacted. The amounts of materials for these specimens were varied so that the heights of the specimens would be approximately 2-1/2 inches and therefore the specimens could be tested by the repeated-load type test and also by the Hveem Stabilometer.

Density Determinations

Density determinations were made on the cylindrical- and slab-type specimens before testing and density determinations were also made on some of the cylindrical- and slab-type specimens after testing. For the slab-type specimens the initial density was determined from dimension and weight measurements and after testing, cores were taken from the center and corners of the slab and density determinations were performed on these cores. Figure 5 shows the cores and cored slab. For the cylindrical-type specimens the water displacement

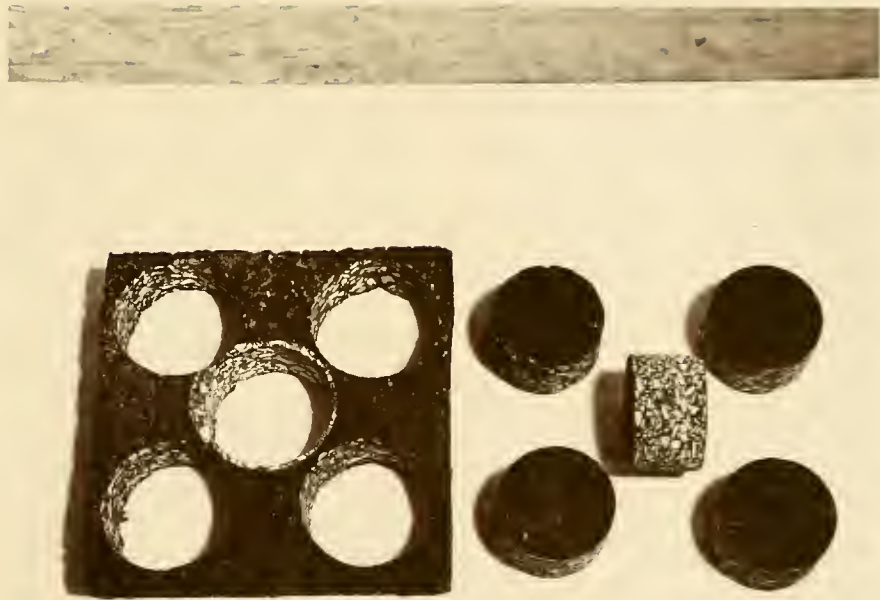


Fig. 5 CORES AND CORED SLAB SPECIMEN

method was used both before and after testing.

After the cylindrical specimen had cooled to room temperature it was weighed in air. It was then submerged in water for one-half hour which allowed the specimen to become partially saturated. It had previously been determined that submerging this size specimen in water for one-half hour allowed it to reach a condition of equilibrium, so that the accurate weight of the specimen submerged in the water could be determined. The specimen was weighed submerged in the water. The specimen was then taken from the water, surface dried and weighed in the saturated-surface-dry condition. The density was then calculated by dividing the weight in air by the weight saturated-surface-dry minus the weight in water. The specimens were then allowed to drain and dry before testing. The aggregate density of the specimens was also calculated by dividing the weight of aggregate by the volume of the specimen.

Repeated-Load Test

The procedure for testing the slab-type specimens was almost the same as for the testing of the cylindrical specimens, and any differences are given at the appropriate steps in the following outline of the procedure.

The specimens were placed in a constant-temperature water bath at $100 \pm 1^{\circ}\text{F}$ before testing. The slab-type specimens were allowed to remain in the water bath 30 minutes and the cylindrical specimens 15 minutes so that they would be at the test

temperature before starting the test. The machine used for the repeated loading was an air motor mounted in a loading frame as shown in Figure 6(4). The numbers on Figure 6 are explained in the key on the page facing the figure. This figure shows the apparatus with the calibration equipment attached. For clarity, the apparatus is shown without the water bath which was used to control the temperature of the specimen. With this apparatus it was possible to apply, hold, and release a load on the specimen to be tested. Appropriate valves and controls were present to admit compressed air to the air motor for a pre-set time interval. The load was transmitted from the air motor by a shaft to a plate which rested on the specimen to be tested. At the end of the pre-set time interval, during which the load remained constant, the load was quickly released by stopping the compressed air from entering the air motor and by opening an exhaust valve. After another time interval, which could also be pre-set, the cycle was repeated.

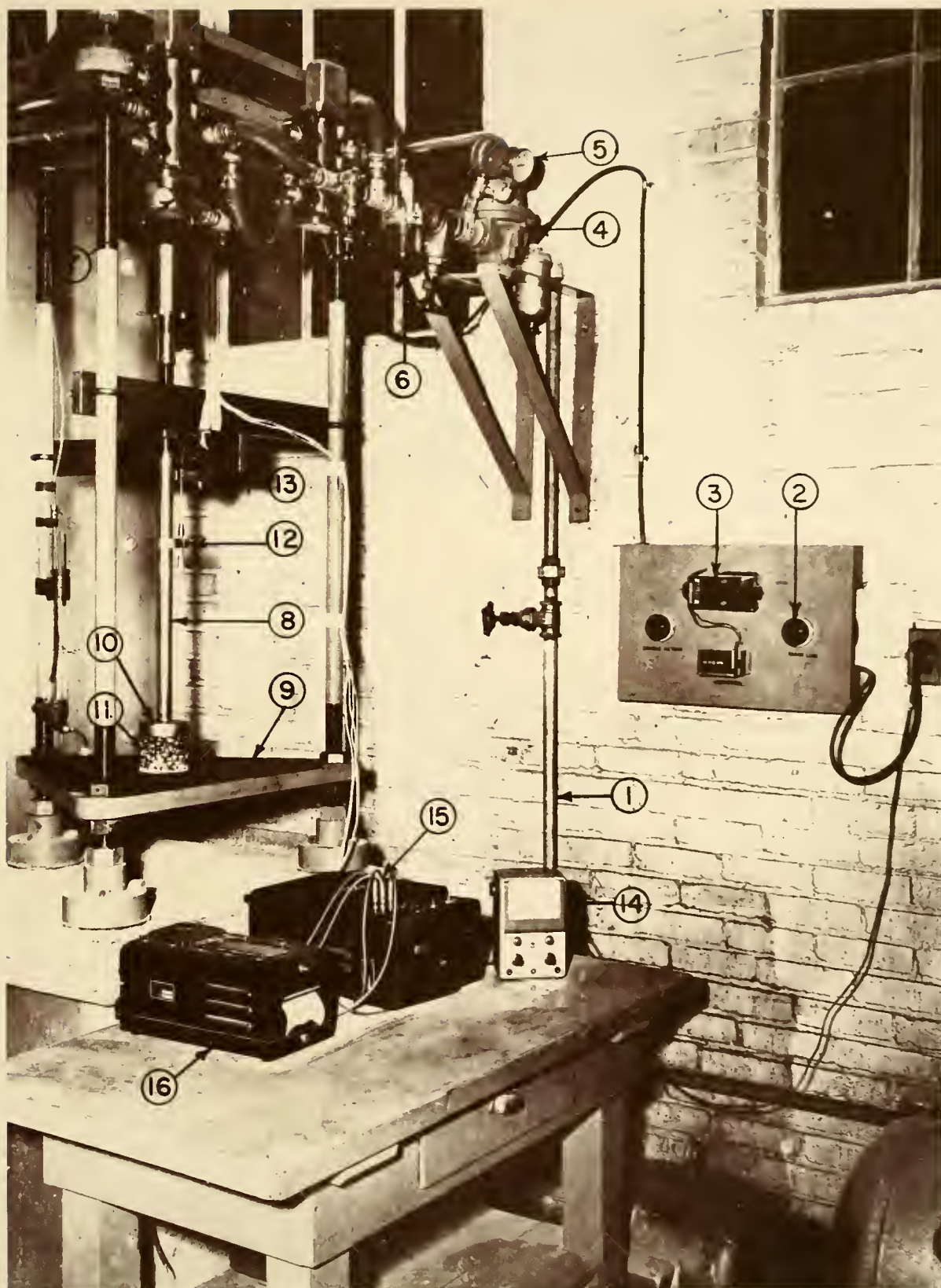
The above describes the basic operation of the repeated load machine. The following is a detailed description of the equipment used with the machine (6):

"Compressed air at 100 to 110 psi outlet pressure was supplied by a Gardner-Denver model 329 LT air compressor, powered by a 7-1/2 hp. electric motor. From the compressor tank a one-inch diameter galvanized pipe led through an air line filter to remove moisture and any foreign particles from the air, and thence into a Grove GB 307-06 Powreactor Dome pressure regulator. This regulator, of the diaphragm type was found to regulate the outlet pressure quite accurately while still permitting the sudden and intermittent flow of air required to produce the repetitive type of loading.

Fig. 6. Repeated-Load Test Apparatus.

Key

1. Air line from air compressor
2. Main-line switch
3. Agastat
4. Grove GB 307-06 Powreactor Dome pressure regulator
5. Pressure gauge
6. Air line lubricator
7. Bellows 8002 FR Power Dome air cylinder
8. Extension rod for loading head
9. Lower platen of testing machine
10. Testing-head
11. Specimen
12. Assembly for supporting core of L.V.D.T.
13. Assembly for holding coil of L.V.D.T.
14. Voltmeter
15. Brush Model BL-320 Universal Analyzer
16. Brush Model BL-292 Oscillograph



"From the pressure regulator the line passed through an air line lubricator and branched to enter two Bellows 4SSV 3/4 Bel-Air electrically-controlled valves, each of which was connected to one end of a Bellows 8002 FR Power Dome air cylinder. This cylinder was mounted vertically to the upper platen of the loading frame and afforded a downward stroke of from zero to two-inches for the loading piston. A loading head attached to the loading piston applied load directly to the samples . . . placed on the lower platen beneath the air cylinder. The total load which was applied could be controlled by adjusting the Powreactor pressure regulator, while both the duration of load and time interval between successive load applications could be regulated through the Bel-Air valve means of an Agastat DED-11 double-acting timer . . . Manual valves and switches were so arranged that one Bel-Air valve could be removed from the system if desired, resulting in a single-acting stroke of the loading piston rather than its normal reciprocating action.

"The Grove regulator could be adjusted to approximately the desired pressure for any test series by observing a dial gauge connected directly to the pressure dome of the regulator . . ."

For the present study only the single-acting stroke was used. A ball attachment was screwed onto the bottom of the loading piston and a four-inch diameter, one-inch thick, stainless steel disc lay on top of the specimen. This disc had a socket machined in the center of the top surface to receive the ball.

A strain dial was attached to the shaft which transmitted the load to the specimen and was used to measure the permanent deformations of the specimen. The strain dial was read at a given number of load repetitions which were chosen so that the points would be somewhat evenly spaced when plotted on a logarithmic scale.

The load durations and intervals between loads were 0.3

and 4.0 seconds, respectively, and these values were held constant for all repeated-load tests. These times values were established by measuring the movement of the loading piston "through the use of a Schaevitz Model .04-0-.04 Linear Variable Differential Transformer (L.V.D.T.), the voltage output from which was passed through a Brush model BL-320 Universal Analyzer and recorded directly as a deflection-time curve on a Brush Model BL-292 oscillograph. The core of the transformer was mounted on the loading piston while the coil was mounted on an arm fixed to the loading frame" (o).

The contact pressure used for all of the cylindrical specimens was 100 psi. Three contact pressures (100, 150, and 200 psi) were used in the testing of the slab-type specimens. The higher contact pressures were used because this type specimen would not fail at the relatively small number of load repetitions being used.

The tests on the cylindrical-type specimens were discontinued at about 80 load repetitions, but the tests on the slab-type specimens were continued until visible signs of failure (cracking) occurred.

Hveem Stabilometer Test

The cylindrical specimens were tested by the Hveem Method as follows (1):

1. Place specimens in an oven at 140°F. for a minimum period of one hour before testing.
2. Adjust the compression machine to obtain a head speed

of 0.05 in. per minute.

3. Adjust the displacement of the Stabilometer to give 2.00 ± 0.05 turns.

4. Adjust stage on Stabilometer so that 2.40 inches of rubber diaphragm will be effective upon the specimen.

5. Place the specimen in the Stabilometer.

6. Raise pressure in Stabilometer to 5 psi.

7. Apply test loads at previously set head speed and record readings of test gauge at test loads of 500 lbs., 1,000 lbs. and each 1,000 lbs. thereafter up to a maximum of 6,000 lbs.

8. Reduce total load on the specimen to 1,000 lbs.

9. Adjust displacement until 5 psi. is recorded on test gauge.

10. Turn displacement handle at two turns per second until 100 psi. is recorded on test gauge.

11. Record the exact number of turns required to increase test gauge pressure from 5 psi. to 100 psi. as displacement on specimen.

The Hveem Stabilometer is shown in Figure 7.



Fig. 7 HVEEM STABILOMETER

RESULTS

The results of the repeated-load and Hveem Stabilometer tests are presented in Tables 6, 7, 8 and 9 (Appendix) along with appropriate composition and density data. The results are discussed in this section and a comparison between test results by the repeated-load and Hveem Stabilometer procedures is made.

The variables in this investigation were aggregate gradation, asphalt content and density or degree of compaction. Two gradations were used, the Corps of Engineers dense gradation for surface mixtures and the Indiana State Highway Department AH Type B surface mixture gradation.

Asphalt contents of 5, 6 and 7 percent by weight of mixture were selected for the Indiana gradation, and an asphalt content of 7 percent by weight of mixture was selected for the Corps of Engineers gradation. The asphalt contents used with the Indiana gradation cover the range of those used in practice. The asphalt content used with the Corps of Engineers gradation was selected to produce a plastic type of mixture and was higher than that usually used in design. Due to a weighing error there was a variation in the percent asphalt content of the specimens as molded. The magnitude of this variation warranted the determination of the percent asphalt content by extraction for all of the specimens. The results

of the extraction tests are given in Tables 6 through 9 of the Appendix.

It was desired to chose the density levels for this study so that they would compare to all conditions of a pavement, from as-constructed to fully traffic-compacted. The minimum bulk density of approximately 138 pounds per cubic foot was chosen for both gradations to compare to the compaction condition of a newly-constructed pavement. Other specimens were compacted to range from this density to the maximum density obtainable, which approached the maximum theoretical density. An attempt was made to obtain an even distribution of the density values between the above limits, but this was not achieved for mixtures of the Corps of Engineers gradation. Density results are presented in Tables 6 through 9 of the Appendix.

Repeated-Load Tests

There were two parameters obtained from the data of the repeated-load tests. One of these was the deformation index, defined as the slope of the straight line of the log-log plot of accumulated permanent deformation versus number of load repetitions (See Figure 8). The other value obtained from the repeated-load test was the permanent deformation per load repetition (See Figure 9). An arithmetic plot of the accumulated permanent deformation per load repetition was drawn and from the plot it was observed that there was a portion of the curve between 20 and 50 load repetitions that approached a

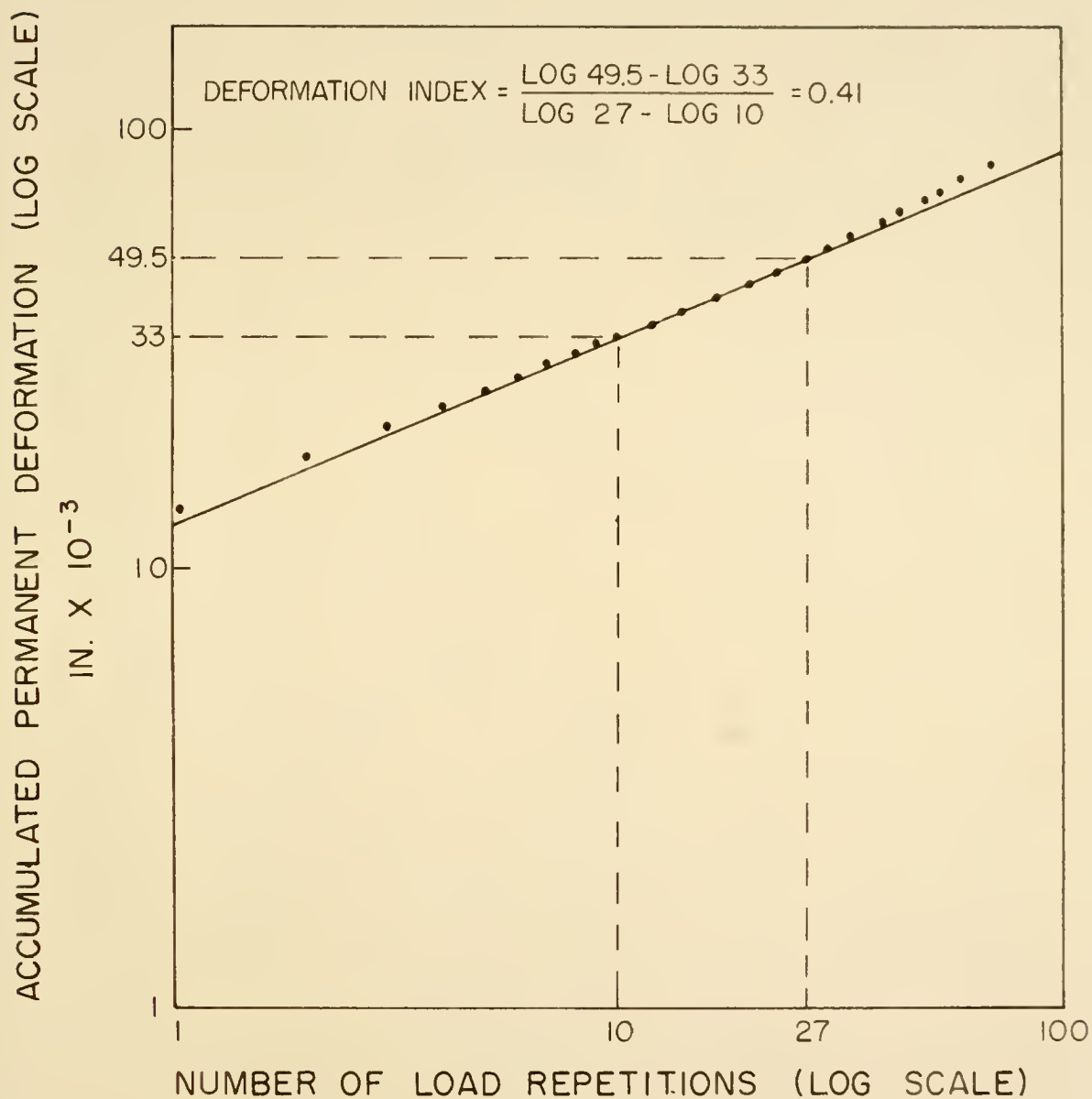


FIG. 8. TYPICAL DATA OF REPEATED-LOAD TEST - LOG-LOG PLOT - CYLINDRICAL SPECIMENS.

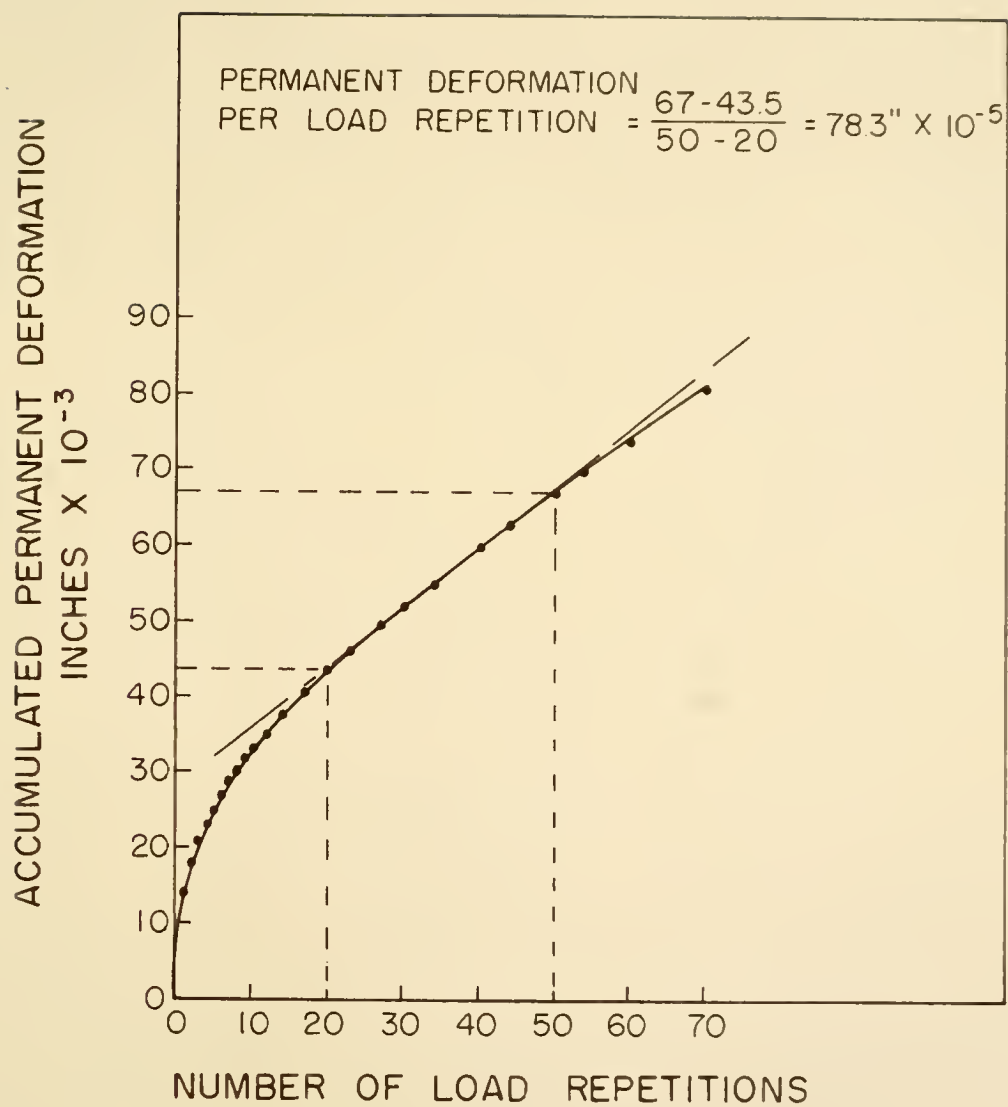


FIG. 9. TYPICAL DATA OF REPEATED-LOAD TEST -
ARITHMETIC PLOT - CYLINDRICAL SPECIMEN

straight line. The values in this portion were used arbitrarily to calculate a value of permanent deformation per load repetition. Table 5 is a typical data sheet from the repeated-load test.

Other parameters for the repeated-load test were investigated for the purposes of this study. However, these two were chosen as being as indicative as any that could be derived from the data obtained.

Cylindrical-Type Specimens

Values for the two parameters obtained from tests on the cylindrical specimens for the two gradations are shown in Tables 6 and 7 of the Appendix. Curves were drawn from these values by selecting specimens of approximately constant aggregate density and plotting curves of percent asphalt content by weight of aggregate versus deformation index and curves of asphalt content versus permanent deformation per load repetition. These curves are shown in Figures 10 through 13. The positions of the curves shown in the figures were established by fitting a curve to calculated average deformation index and permanent deformation per load repetition values for mixtures of approximately equal asphalt contents.

For the Indiana gradation the two parameters, Figures 10 and 12, give approximately the same shape curves for the three density levels. For the two lower density levels there is a decrease and then an increase in the parameter values as the asphalt content is increased. It was postulated that for the

Table 5

Typical Data Sheet for Repeated-Load Test
Cylindrical-Type Specimen

Temperature: 100°F

Date: July 7, 1958

Pressure: 100 psi

Specimen: B-27

Number of Load Repetitions	Accumulated Permanent Deformation in. x 10 ⁻³	Permanent Deformation per Load Repetition in. x 10 ⁻³
0	0	0
1	14	14
2	18	4
3	21	3
4	23	2
5	25	2
6	27	2
7	29	2
8	30	1
9	32	2
10	33	1
12	35	2
14	37.5	2.5
17	40.5	2.5
20	43.5	3
23	46	2.5
27	49.5	3.5
30	52	2.5
34	55	3
40	60	5
44	63	3
50	67	4
54	70	3
60	74	4
70	81	7

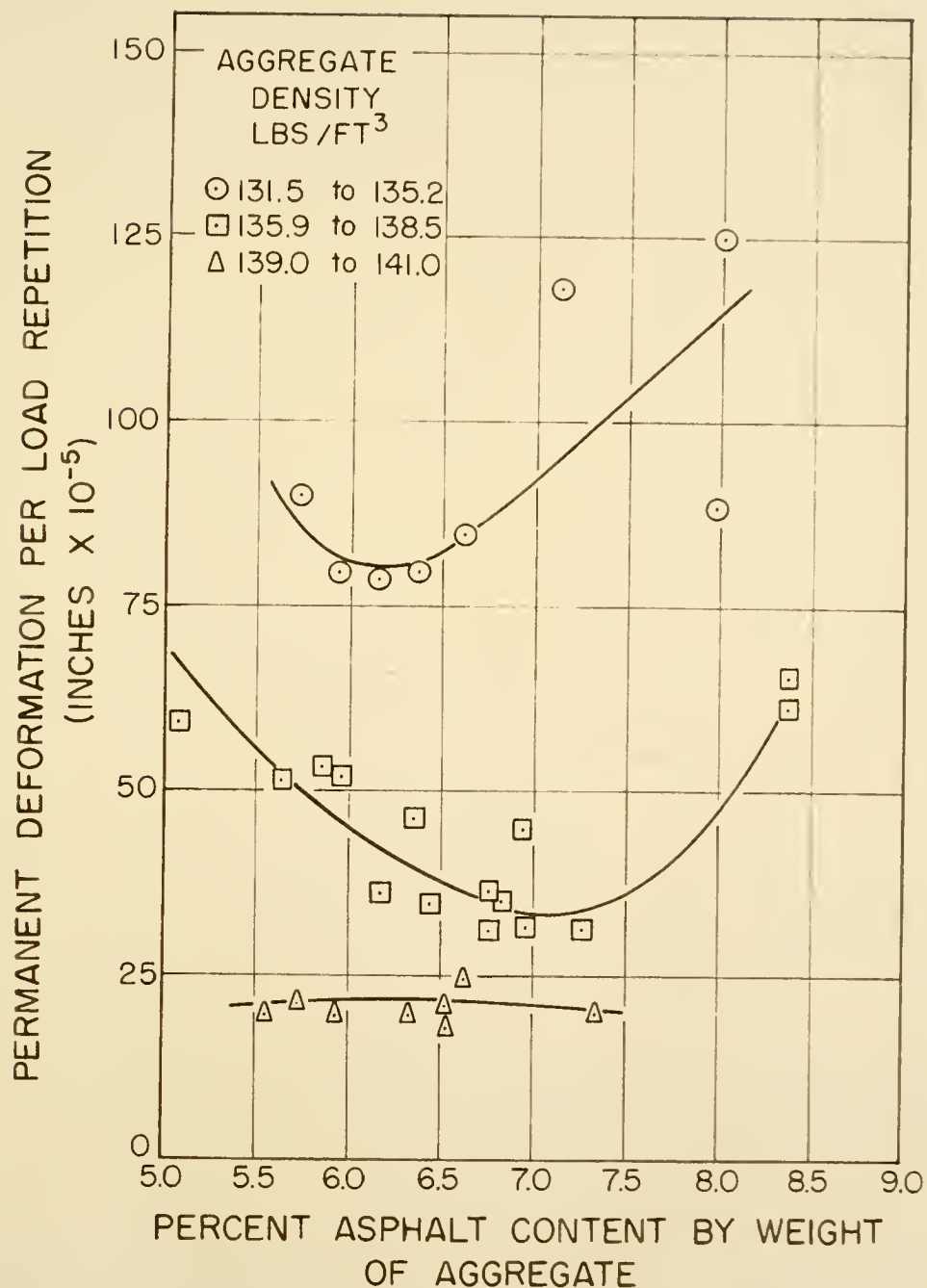


FIG. 10. REPEATED-LOAD TEST RESULTS - INDIANA GRADATION - CYLINDRICAL-TYPE SPECIMENS - PERMANENT DEFORMATION PER LOAD REPETITION.

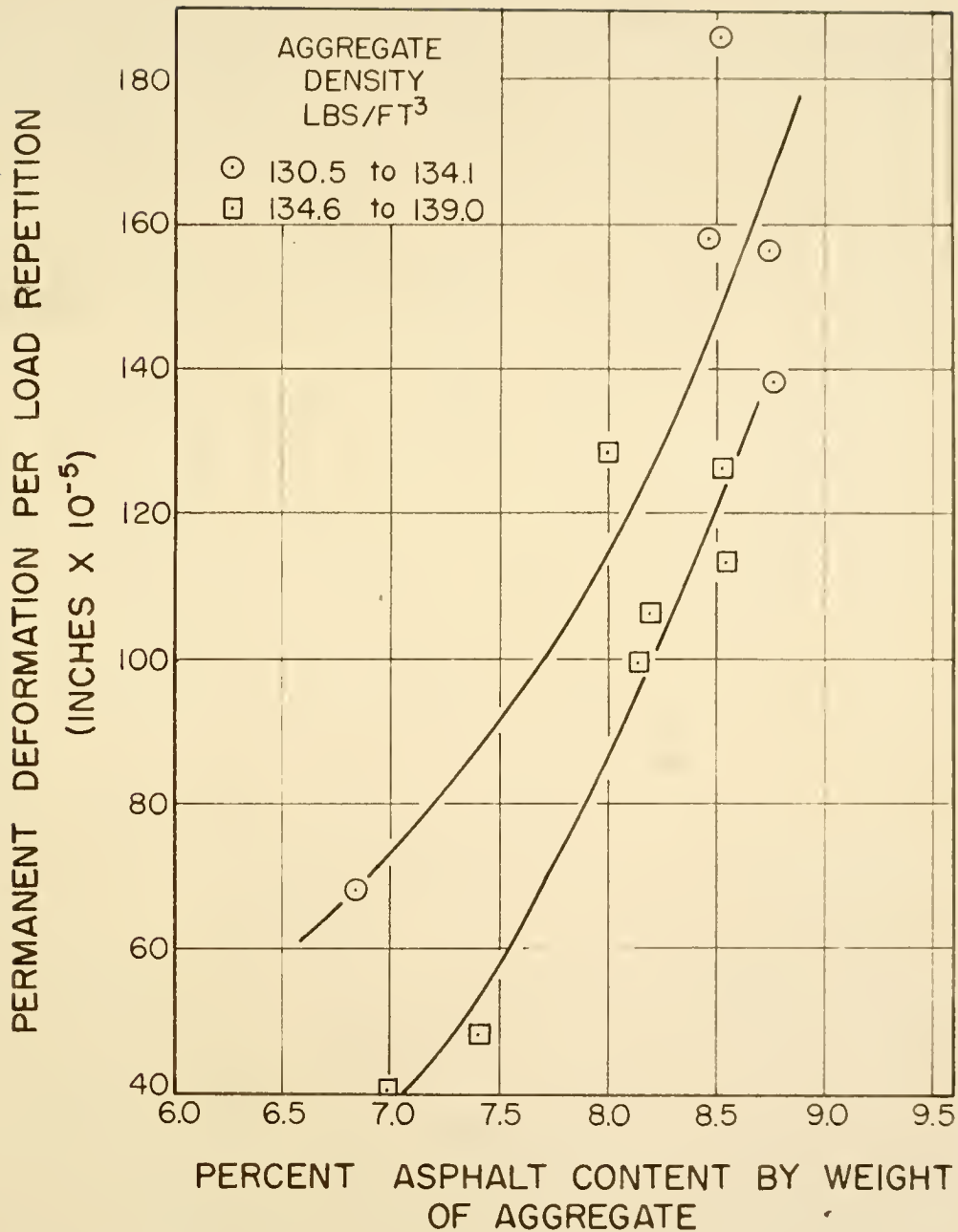


FIG. II. REPEATED-LOAD TEST RESULTS - CORPS. OF ENGINEERS GRADATION - CYLINDRICAL-TYPE SPECIMENS - PERMANENT DEFORMATION PER LOAD REPETITION.

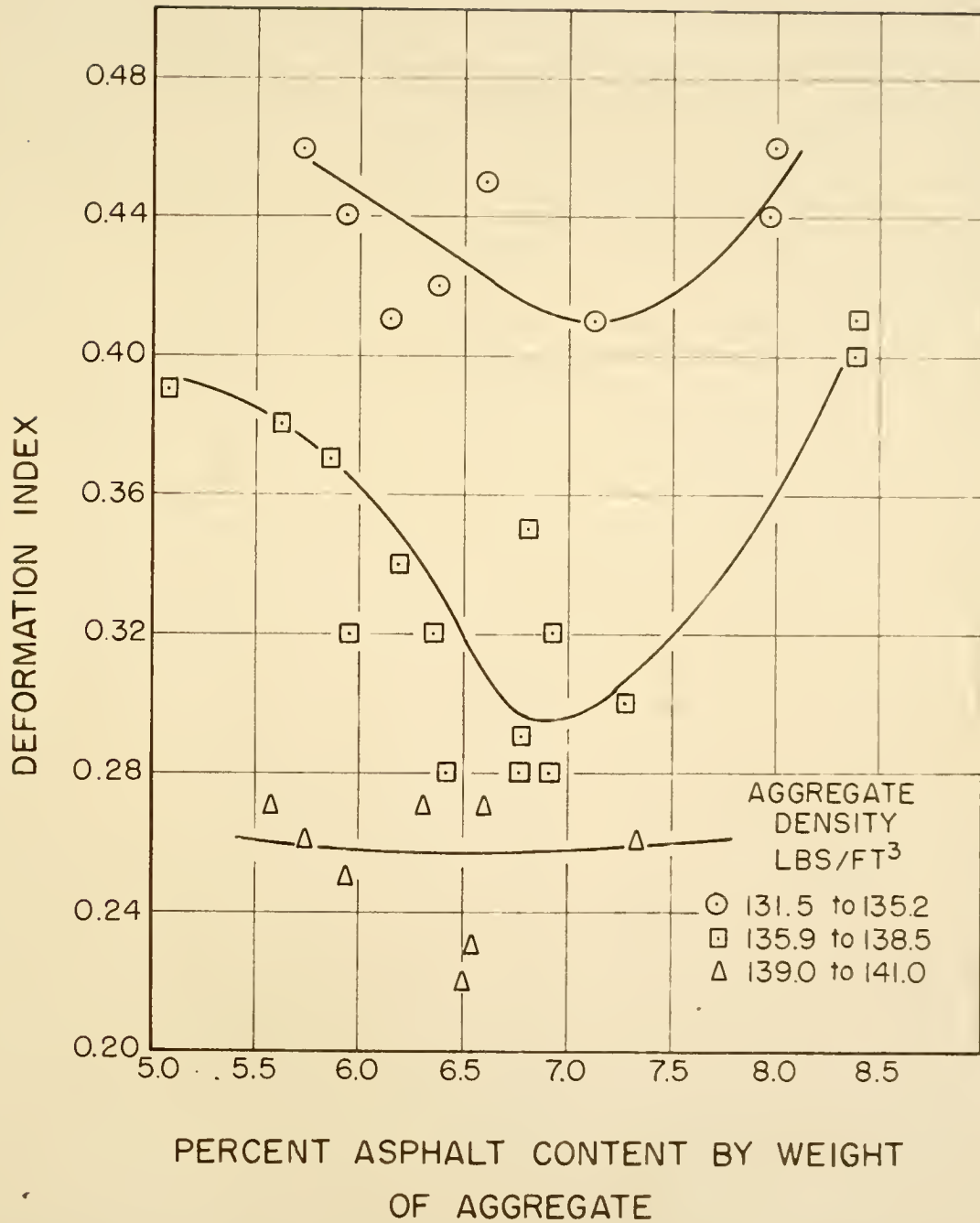


FIG. 12. REPEATED-LOAD TEST RESULTS - INDIANA GRADATION - CYLINDRICAL-TYPE SPECIMENS - DEFORMATION INDEX.

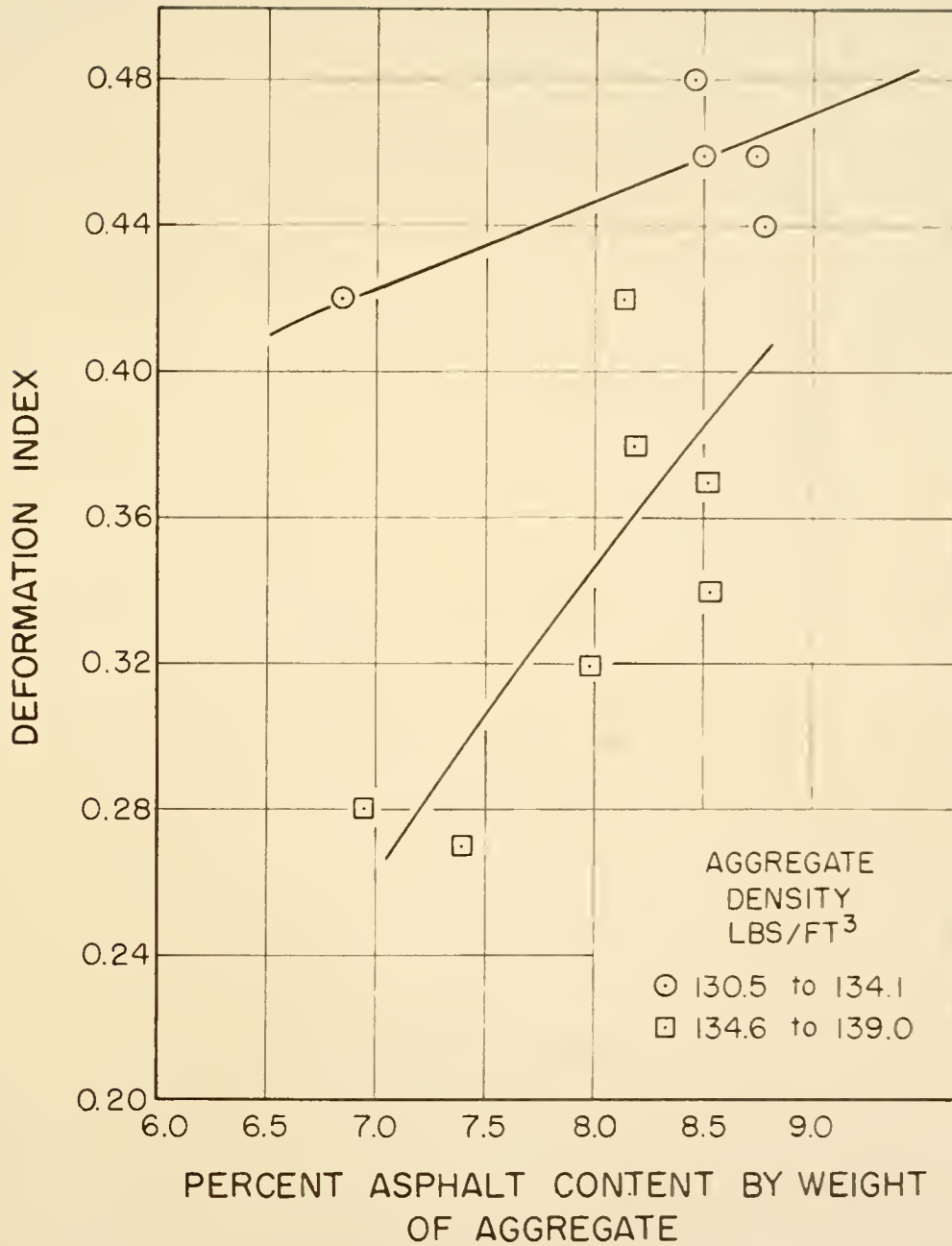


FIG. 13. REPEATED-LOAD TEST RESULTS - CORPS. OF ENGINEERS - CYLINDRICAL-TYPE SPECIMENS - DEFORMATION INDEX.

initial part of these two curves the parameter values decreased because the added amount of asphalt acted as a cementing agent. This relationship is true only up to a certain asphalt content and then the added amount of asphalt acts as a lubricant in the mixture, perhaps because void continuity is lost as the mixture approaches saturation. When the minimum condition is reached, greater parameter values are obtained. For the highest density level, the curves show that there is very little change in parameter value with change in asphalt content. The lack of change in parameter value with increase of asphalt content in the initial part of this curve was probably due to a thinner asphalt film, caused by the higher aggregate density, acting to allow less deformation. There is a lack of data for mixtures with asphalt contents greater than 7.5 percent. It was supposed that if specimens could have been compacted for this portion, larger parameter values would have been obtained. Then this portion of the curves would have the same shape as the corresponding portions of the curves for the other two density levels.

For the Corps of Engineers gradation, results were obtained only for the two lower density levels. Curves of the same approximate shape were obtained for the two parameters. For these curves the portion at the lower asphalt contents is not well defined since there is a lack of data in this range. An increase of the parameter values with an increase in asphalt content is shown because the range of asphalt contents studied for the Corps of Engineers gradation was in the upper part of

the range of those used with the Indiana gradation, and for this high range of asphalt contents, the lubricating effect takes place.

Density determinations were performed on some specimens after testing by means of the repeated-load test (Table 10 of Appendix), and it was found that the specimens of all mixtures were less dense after testing than before testing. This difference in density caused by the repeated-load test varied from one to four pounds per cubic foot regardless of gradation, density and asphalt content. Since the temperature at which the tests were made was $100 \pm 1^{\circ}\text{F.}$, and there was no confining pressure, the specimens expanded laterally. This density study shows that for this type of specimen there was no densification caused by the repeated-load that was applied.

Slab-Type Specimens

Only five of the slab-type specimens were tested under the same test conditions (100 psi. pressure and 100°F. temperature) as the cylindrical specimens. They were of the Indiana gradation with approximately 7 percent asphalt content by weight of mixture. The size of each slab was 12 by 12 by 2-1/2 inches. The results from the repeated-load test on the slab-type specimens are given in Table 11 of the Appendix. From the density determinations on cores taken from the slabs it was estimated that the bulk density of the material directly beneath the loading head was 143 pounds per cubic foot. The 7 percent asphalt content by weight of mixture corresponds to

7.52 percent asphalt content by weight of aggregate. The bulk density of 143 pounds per cubic foot corresponds to an aggregate density of 133.4 pounds per cubic foot.

By cutting the slab-type specimens into sections 2-inches square by 2-1/2 inches deep, and performing density determinations on these sections, it was found that the specimens were not of a uniform density when using either method to compact the specimens. There was a difference in density of about 6 pounds per cubic foot between the center and the outside sections of the specimen. Since the slab specimens were not of a uniform density it was impossible to determine the change in density, due to testing, of the loaded portion of the specimen.

The average deformation index for these specimens was 0.30. The straight-line portion of the arithmetic plots of accumulated permanent deformation versus number of load repetitions (Figure 9) was not reached for the slab-type specimens at 20 repetitions of load (probably due to the support of the surrounding material) and the portion between 40 and 60 repetitions of load was selected for calculation of a parameter value since this portion did approach a straight line. An average value of 49×10^{-5} inches per load repetition was obtained for the permanent deformation per load repetition parameter.

Comparison of Cylindrical and Slab-Type Specimens

The influence of specimen size on the results of the

repeated-load tests is shown by comparing the strength parameters of the two types of specimens. The average deformation index for the Indiana gradation slab-type specimen at 7.52 percent asphalt content by weight of aggregate and an aggregate density of 133.4 pounds per cubic foot was 0.30. For the cylindrical-type specimen of the same gradation, percent asphalt content, and aggregate density, the deformation index was 0.42. This means that there was less permanent deformation for the slab-type specimen than for the cylindrical specimen at a comparable number of load repetitions. This result is logical since the material surrounding the portion being tested gave support to the tested portion. This is also shown by the values for the parameter permanent deformation per load repetition, since average values of 49×10^{-5} inches per load repetition for the slab-type specimens and 100×10^{-5} inches per load repetition for the cylindrical-type specimens were obtained.

Hveem Stabilometer Tests

The results of the Hveem Stabilometer tests are given in Tables 8 and 9 of the Appendix. Figure 14 shows curves of Hveen Stability versus percent asphalt content by weight of aggregate for the Indiana gradation at approximately the same values of aggregate density as used for the curves of the repeated-load tests. From Figure 14 it can be seen that at any of the three density levels, the Stabilometer value decreases with an increase in asphalt content. Also, at any

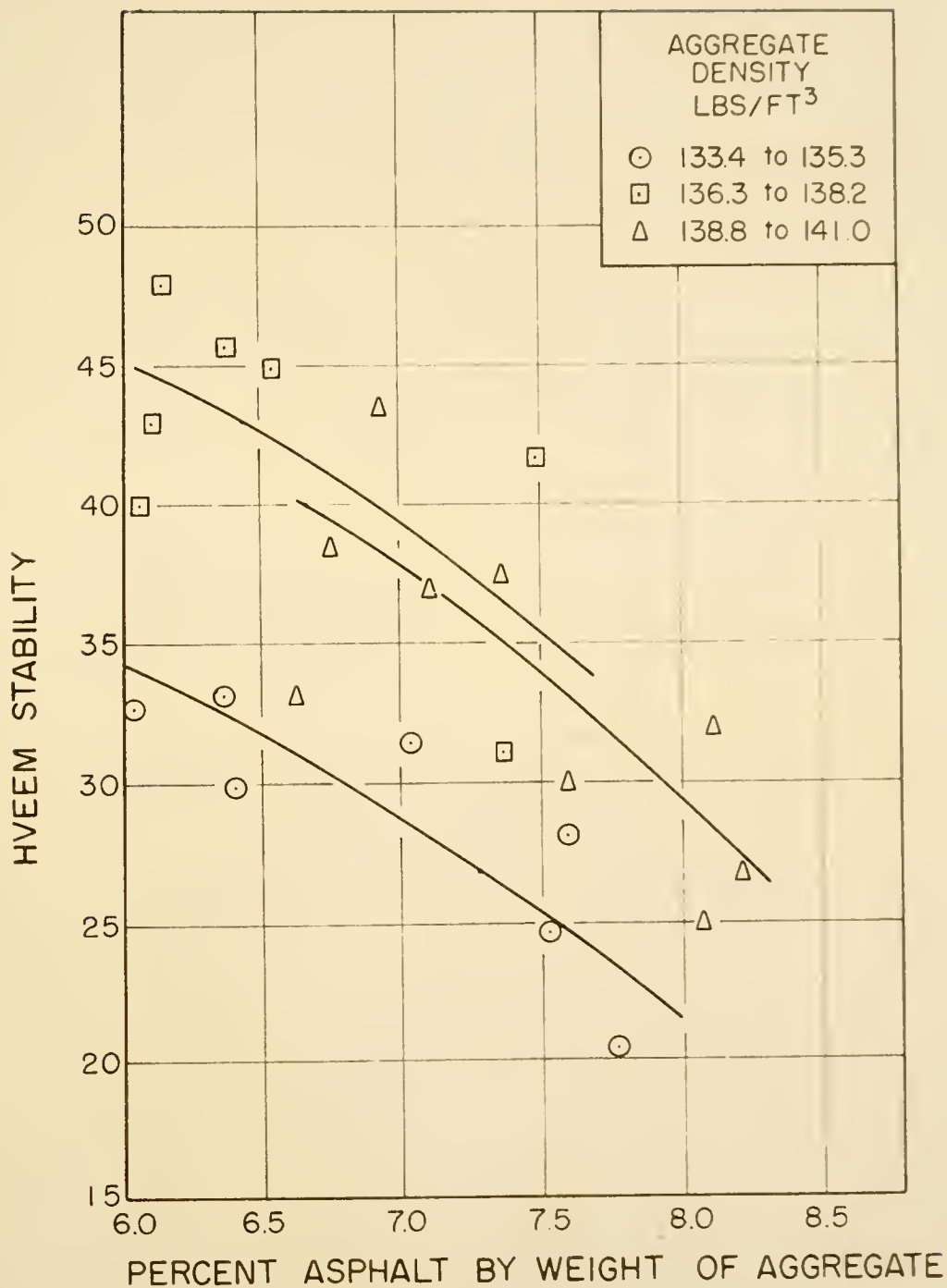


FIG. 14. HVEEM STABILOMETER RESULTS - INDIANA GRADATION.

given asphalt content within the range of those studied there is an increase in stability with an increase in aggregate density.

Only five Hveem Stabilometer values for the Corps of Engineers gradation with approximately 7 percent asphalt content were obtained because the mixture was so unstable that most of the tests could not be completed. Since there were only five Hveem Stabilometer values obtained and the range of asphalt content was small, the effect of asphalt content in this case was not determined. Also, Hveem Stabilometer values for mixtures of the two gradations cannot be compared because adequate Hveem Stabilometer values were not obtained from the mixture of the Corps of Engineers gradation at the asphalt contents used.

Comparison of Results from Hveem Stabilometer and Repeated-Load Tests

The Hveem Stabilometer value is determined by the following expression (1):

$$S = \frac{22.2}{\frac{(P_h D_2)}{(P_v - P_h)} + 0.222}$$

where S = relative stability

D_2 = displacement on specimen

P_v = vertical pressure at 400 psi. (5,000 lbs. total load)

P_h = horizontal pressure corresponding to $P_v = 400$ psi.

It can be demonstrated that as the type of material is varied from rigid to fluid, the Stabilometer value is respectively varied from 100 to zero. This concept can be observed from the curves of Figure 14 which show that the Stabilometer value increases as the density increases. The repeated-load test results show a similar relationship in that as the specimens varied from less dense to more dense, the parameter values varied from high to low. Figures 10, 11, 12 and 13 demonstrate this relationship. The parameters obtained from the repeated-load test results appear to provide some measure of the plastic properties of the bituminous mixture, with a larger value corresponding to a more plastic mixture.

A comparison cannot be made between the curves of the repeated-load test parameter values and the Hveem Stabilometer values for the Corps of Engineers gradation because adequate Hveem Stabilometer results were not obtained for this gradation. In comparing the parameter values from the repeated-load test for the Indiana gradation with the Hveem Stabilometer values of the Indiana gradation it can be seen that, for comparable ranges of asphalt content at the two lower density levels, the repeated-load parameter values decrease and then increase while the Hveem Stabilometer values decrease steadily. When making the same comparison at the high density level it can be seen that the parameter values of the repeated-load test remain approximately constant with an increase in asphalt content, while the Hveem Stabilometer values decrease with an increase in asphalt content.

From these comparisons of results it appears that the mixtures are evaluated differently by the two test methods. This result was anticipated since the parameter values of the repeated-load test are calculated from permanent deformation values obtained by applying a repeated-load of constant magnitude to the specimen, while the Hveem Stabilometer values are calculated from stress values obtained by applying an increasing load at a constant rate of deformation.

CONCLUSIONS

Based on the results of this study, the following conclusions seem justified. This was a laboratory study of limited scope and the conclusions can only be applied to those conditions that were used in this study.

1. Parameters can be obtained from the repeated-load test, as described in this investigation, which give a measure of the deformation characteristics of bituminous concrete surface mixtures.

2. The parameter values obtained from the repeated-load test cannot be evaluated by comparing them with Hveem Stabilometer values, since the repeated-load test gives a measure of deformation characteristics for a repeated constant load, while the Hveem Stabilometer test gives a measure of the stress-transmission characteristics of the mixtures studied.

3. Since the specimens tested by the repeated-load test decreased rather than increased in density and therefore did not conform to the field condition of densification due to traffic compaction, it was concluded that the results from this investigation were not suitable for evaluating bituminous concrete surface mixtures with respect to rutting and shoving.

SUGGESTIONS FOR FURTHER RESEARCH

It is suggested that a strength value be obtained from repeated-load test data. In order to obtain a strength value it is necessary to obtain a failure criterion. This might be accomplished by a correlation study which would include obtaining slabs or cores from pavements at various stages of rutting and shoving and testing them by use of the repeated-load and Hveem Stabilometer tests. It is also suggested that more load repetitions be used in the repeated-load test, so that the permanent deformations at failure might be obtained and studied.

Another project that might provide useful information is the repeated-load testing of slab-type specimens compacted with the kneading compactor. A slab-type specimen is desirable because it more closely approximates the road prototype. If a suitable slab-type specimen can be obtained, it is believed that densification will occur to the loaded portion of the specimen using a repeated-load type of test. The use of a confining pressure with the repeated-load test might also make it possible to obtain the desired densification. This effect should provide information useful in solving the rutting and shoving problem.

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APPENDIX

Table 6
Results of Repeated-Load Test on Cylindrical Specimens - Indiana Gradation

Specimen Number	Asphalt Content by Weight of Mixture Percent by Extraction	Bulk Density lbs/ft ³	Aggregate Density lbs/ft ³	Asphalt Content by Weight of Aggregate Percent	Permanent Deformation per Load Repetition in. x 10 ⁻⁵	Deformation Index
C-12	6.64	142.1	131.5	7.12	118.3	0.41
B-27	5.79	140.4	132.2	6.15	78.3	0.41
C-13	7.41	143.5	133.0	8.00	125.0	0.46
A-13	5.41	141.7	134.0	5.72	90.0	0.46
B-31	6.19	142.7	134.1	6.00	85.0	0.45
C-14	7.37	145.0	134.3	7.97	88.3	0.44
B-20	5.98	143.2	134.7	6.37	80.0	0.42
B-21	5.60	143.0	135.2	5.94	80.0	0.44
C-19	7.64	147.0	135.9	8.37	61.7	0.41
B-13	6.47	145.3	135.9	6.91	45.0	0.28
C-20	7.74	145.2	136.0	8.39	63.3	0.40
A-23	5.62	144.1	136.1	5.95	51.7	0.32
A-25	5.54	144.0	136.2	5.86	53.4	0.37
A-12	4.83	143.2	136.3	5.08	58.3	0.39
B-4	6.34	145.8	136.8	6.77	36.7	0.28
B-15	6.02	145.8	136.9	6.42	35.0	0.28
C-10	6.78	147.0	137.3	7.27	31.7	0.30
A-19	5.96	146.2	137.5	6.35	46.7	0.32
B-10	6.47	147.7	137.6	6.92	31.7	0.29
C-3	6.38	148.9	138.2	6.81	35.0	0.35
B-1	5.82	146.9	138.3	6.18	36.7	0.34
A-1	5.31	146.2	138.4	5.61	51.7	0.38
C-5	6.35	147.9	138.5	6.78	31.7	0.29

Table 6 (Continued)

Specimen Number	Asphalt Content of Mixture Percent by Extraction	Bulk Density lbs/ft ³	Aggregate Density lbs/ft ³	Asphalt Content of Aggregate Percent	Permanent Deformation per Load Repetition in. x 10 ⁻⁵	Deformation Index
B-12	6.20	138.2	139.0	6.61	25.0	0.27
B-8	6.84	149.4	139.2	7.34	20.0	0.26
A-5	5.62	149.0	140.0	5.95	20.0	0.25
B-19	5.94	148.9	140.0	6.31	20.0	0.27
A-6	5.29	148.0	140.1	5.59	20.0	0.27
A-17	6.15	149.1	140.1	6.55	18.3	0.23
A-7	5.43	148.9	141.0	5.74	21.6	0.26
B-29	6.12	149.7	141.0	6.51	21.6	0.22

Table 7

Results of Repeated-Load Test on Cylindrical Specimens - Corps of Engineers Gradation

Specimen Number	% Asphalt Content by Weight of Mixture Percent by Extraction	Bulk Density lb/ft ³	Aggregate Density lbs/ft ³	% Asphalt Content by Weight of Aggregate Percent	Permanent Deformation per Load Repetition in. x 10 ⁵	Deformation Index
D-9	7.83	141.2	130.5	8.51	186.7	0.46
D-31	6.40	140.0	131.1	6.84	68.3	0.42
D-4	8.03	144.8	133.2	8.74	156.7	0.46
D-2	8.08	145.7	133.8	8.78	138.3	0.44
D-3	7.80	145.6	134.1	8.46	158.3	0.48
D-5	7.53	145.1	134.6	8.13	100.0	0.42
D-8	7.56	146.0	135.2	8.18	106.7	0.38
D-19	7.80	146.8	135.3	8.52	126.7	0.37
D-7	7.85	146.9	135.6	8.53	113.3	0.34
D-1	7.39	147.8	137.0	7.98	128.3	0.32
D-15	6.89	147.8	137.8	7.40	48.3	0.27
D-20	6.49	148.8	139.0	6.94	40.0	0.28

Table 8

Results of Hveem Stabilometer Test
Indiana Gradation

Specimen Number	% Asphalt Content by Weight of Mixture Percent by Extraction	Bulk Density lbs/ft ³	Aggregate Density lbs/ft ³	% Asphalt Content by Weight of Aggregate Percent	Hveem Stability
B-32	7.00	143.0	133.4	7.52	22.0
A-1	6.01	141.2	134.3	6.40	29.8
A-22	5.73	142.6	134.0	6.08	32.5
C-16	7.13	144.8	134.7	7.78	20.8
B-5	6.59	144.1	135.0	7.06	31.4
B-24	7.07	145.2	135.2	7.60	28.0
A-26	5.99	143.9	135.3	6.38	33.2
C-6	7.60	147.4	136.3	8.22	26.7
C-7	7.47	147.7	136.7	8.08	19.9
B-14	6.62	146.3	136.8	7.09	36.9
C-9	7.51	148.0	137.0	8.13	31.8
B-2	6.20	146.0	137.2	6.62	33.0
B-9	6.32	146.9	137.6	6.75	38.3
B-17	6.47	147.4	137.9	6.92	43.4
C-21	6.85	148.0	137.9	7.30	37.2
C-1	7.06	148.8	138.2	7.60	30.0
C-2	6.95	149.0	138.8	7.48	41.4
A-9	5.75	147.5	139.1	6.11	42.7
B-7	5.98	148.5	139.6	6.37	45.5
B-26	6.87	149.8	139.9	7.37	31.0
A-4	6.15	149.1	140.1	6.55	44.8
B-11	5.73	148.8	140.2	6.07	39.9
A-18	5.78	147.8	141.0	6.14	47.7

Table 9
Results of Hveem Stabilometer Test
Corps of Engineers Gradation

Specimen Number	% Asphalt Content By Weight of Mixture by Extraction	Bulk Density Lbs/ft ³	Aggregate Density lbs/ft ³	% Asphalt Content By Weight of Aggregate Percent	Hveem Stability
D-30	7.32	140.2	130.1	7.90	14.0
D-32	7.60	143.5	132.8	8.30	10.4
D-12	7.84	146.2	134.9	8.50	10.5
D-14	8.10	147.2	135.5	8.81	12.5
D-16	7.49	147.3	136.5	8.09	11.3

Table 10

Density Determinations of Cylindrical Repeated-load
Test Specimens

Specimen Number	Aggregate Density lbs/ft ³	Bulk Density Before Testing lbs/ft ³	Bulk Density After Testing lbs/ft ³	Difference in Bulk Density lbs/ft ³
Indiana Gradation				
A-1	138.4	146.2	143.0	3.2
A-10		147.0	145.3	1.7
A-11	136.7	144.8	142.1	2.7
A-12	136.5	143.2	140.2	3.2
A-13	134.0	141.7	138.0	3.7
A-15		150.7	149.6	1.1
A-17	140.1	149.1	148.0	1.1
A-19	137.5	146.2	144.2	2.0
A-20	134.3	141.0	139.3	1.7
A-23	136.1	144.1	142.6	1.5
Corps of Engineers Gradation				
D-1	137.0	147.8	146.4	1.4
D-20	139.0	148.8	148.0	0.8
D-21	138.0	148.1	147.8	0.3

Table 11

Results of Repeated-Load Test - Indiana Gradation - Slab Specimens 12 x 12 x 2-1/2 inches

Specimen Number	Asphalt Content by Weight of Aggregate Percent	Bulk Density lbs/ft ³ (Estimated)	Aggregate Density lbs/ft ³	Asphalt Content by Weight of Mixture Percent (Approximate)	Permanent Deformation per Load Repetition in. x 10 ⁻⁵	Deformation Index
9	7.52	143	133.4	7	45	0.30
12	7.52	143	133.4	7	55	0.30
14	7.52	143	133.4	7	45	0.29
15	7.52	143	133.4	7	5	0.32
21	7.52	143	133.4	7	45	0.30

